Molecular gas properties of HI monsters probed by the ALMA

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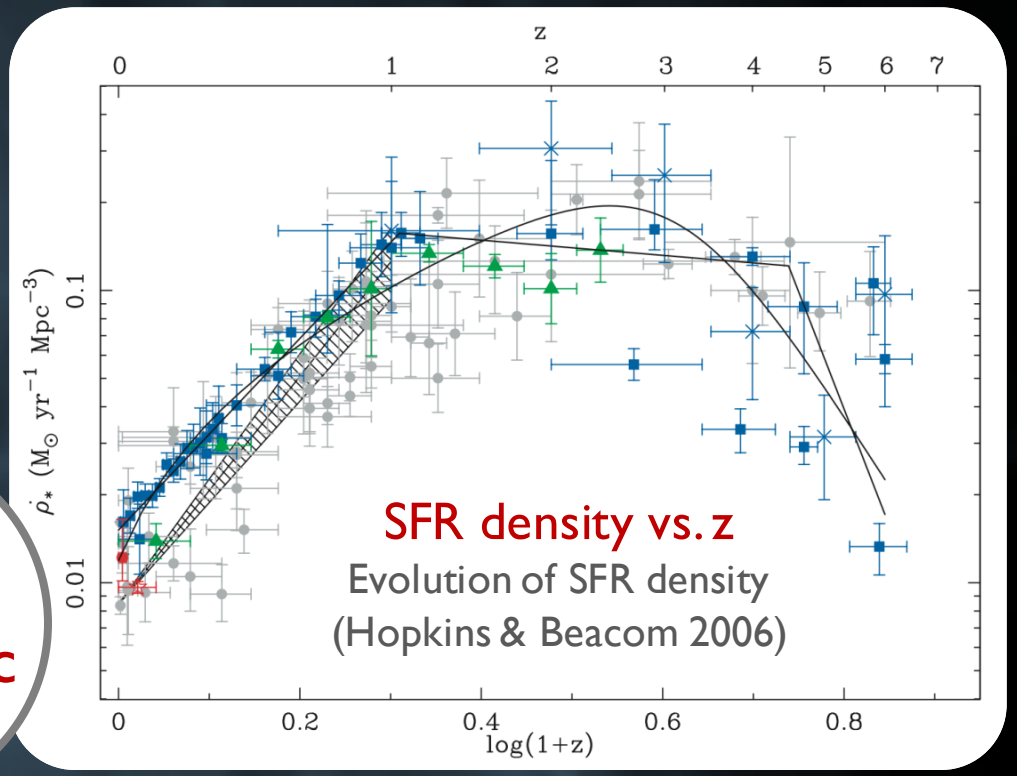
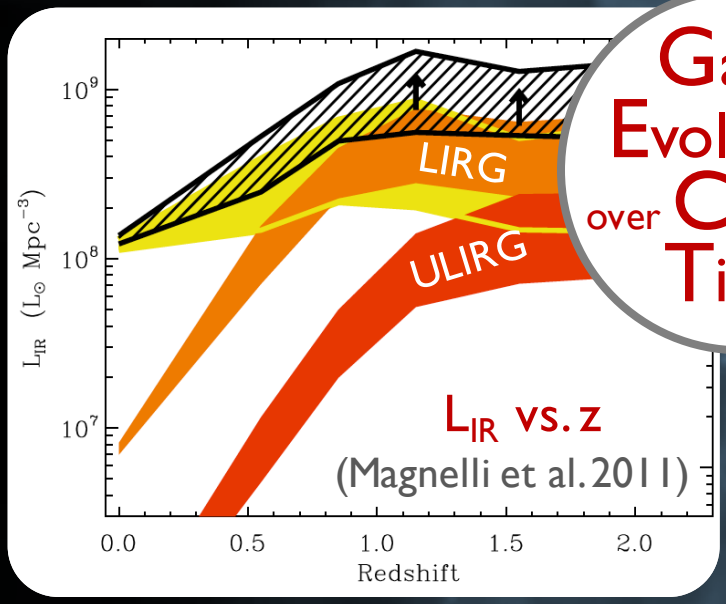
Background image credits: U. Maio & P. Creasey

MW-like galaxies need extra gas fuel to maintain the current star formation rate (e.g. Putman 2006) + gas fraction for such galaxies are expected to be much higher in the earlier epochs (e.g. Madau et al. 1996)





Galaxy Evolution over Cosmic Time

→ Also supported by the time evolution of comoving IR energy density in ultraluminous infrared galaxies (ULIRGs, e.g. LeFloc'h et al. 2005; Magnelli et al. 2011)

→ Gas-rich progenitors?

Discovery of GAS-Rich galaxies

VERY gas-rich galaxies are newly found as we probe more distant universe !!!

E.g. Cantinella et al. (2008) in HI, Daddi et al. (2008) in CO

As commonly believed and adopted in simulations (Dutton et al. 2010),

Q Is a large atomic gas reservoir always associated with a large molecular gas reservoir, and hence high SFR?

Q Can gas accretion rate be directly translated into SFR and stellar mass build-up as theoretically predicted?

→ Construction of HI monster sample for CO follow-up

HI Monster Sample

top 20 galaxies in HI mass selected from the ALFALFA catalog (as of March 2008; Haynes et al. 2011) – $M_{HI} > 3 \times 10^{10} M_{sun}$

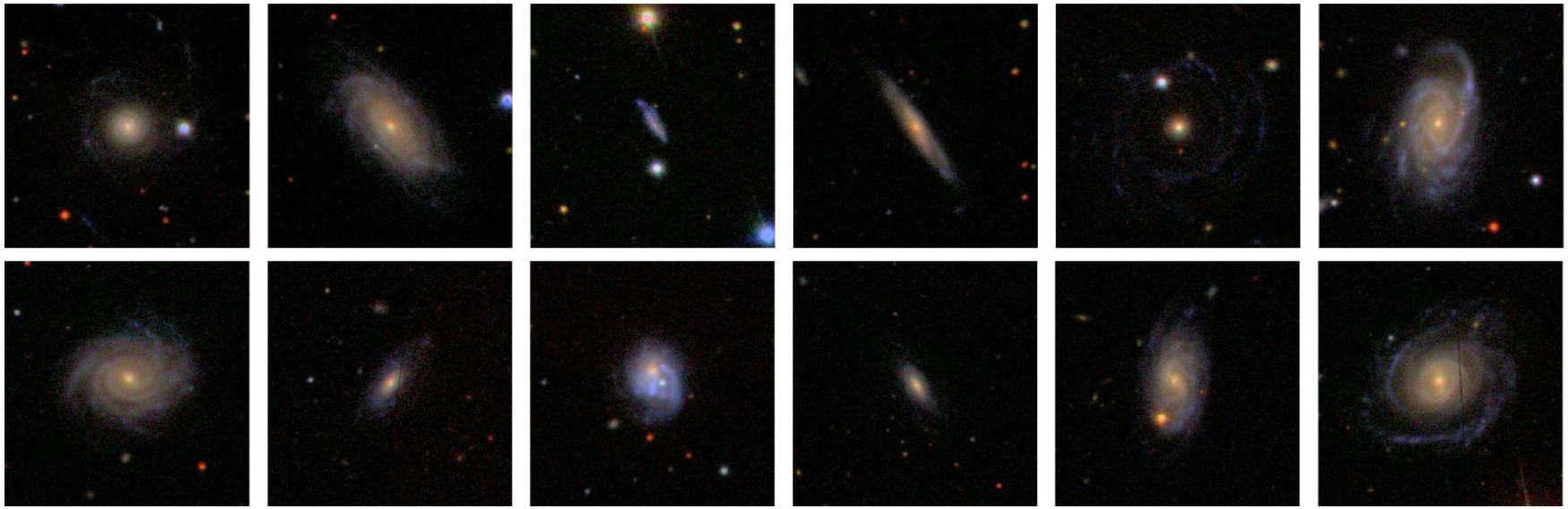
+ 8 low surface brightness galaxies with large HI mass (private comm. w/ S. Schneider) – $M_{HI} > 1.5 \times 10^{10} M_{sun}$

In the redshift range of $\boxed{0.04} < z < \boxed{0.08}$

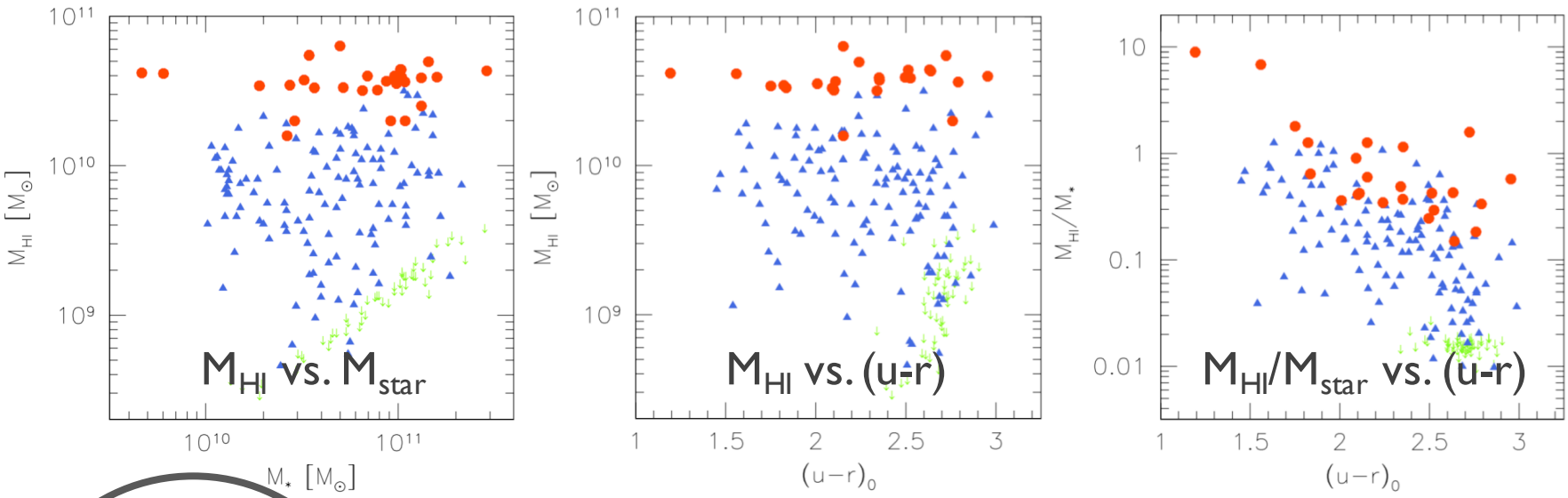
Limited by the frequency coverage of the receiver

ALFALFA depth (March 2008)

Examples of HI monsters: mostly disky, yet various morphology and color



HI monsters (orange) + GASS sample (~300 $M_{star} > 1 \times 10^{10} M_{sun}$; Saintonge et al. 2011)



HI Monster Sample

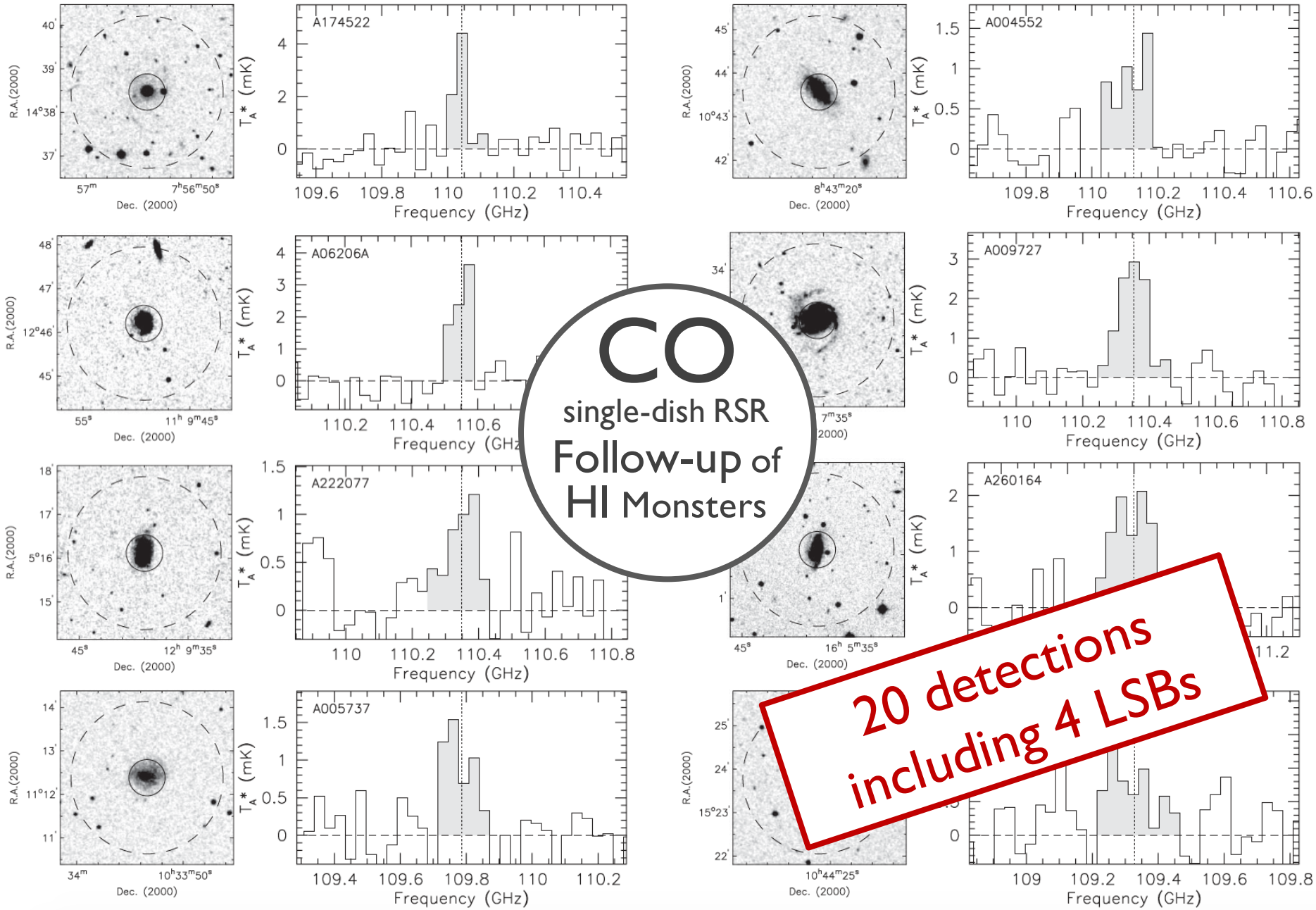
Stellar mass/color widely distributed but all HI-rich

→ Representatives of local HI-rich systems

→ i.e. Good analogies of high-z gas-rich galaxies

→ CO single-dish follow-up (2008-9) using Five College Radio Astronomy Observatory + redshift search receiver

(ultra-wide band spectrometer developed for the LMT – 73 to 110 GHz)



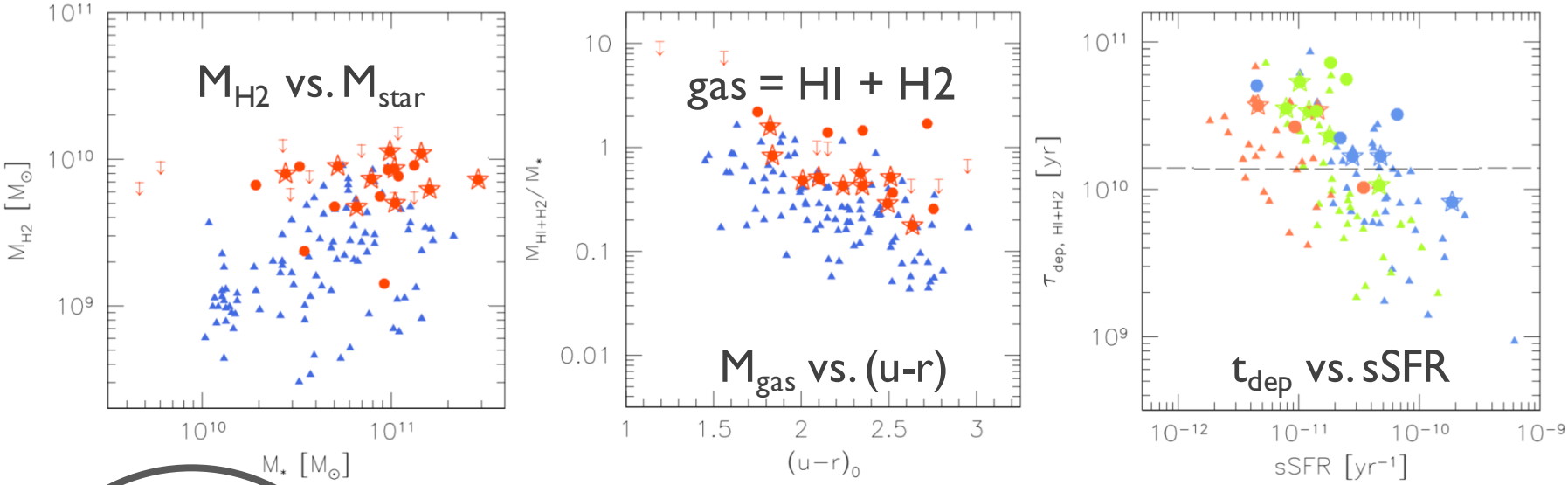
CO

single-dish RSR

Follow-up of HI Monsters

20 detections including 4 LSBs

12CO(1-0) single-dish follow-up of HI monsters (Lee, Chung, et al. 2014)



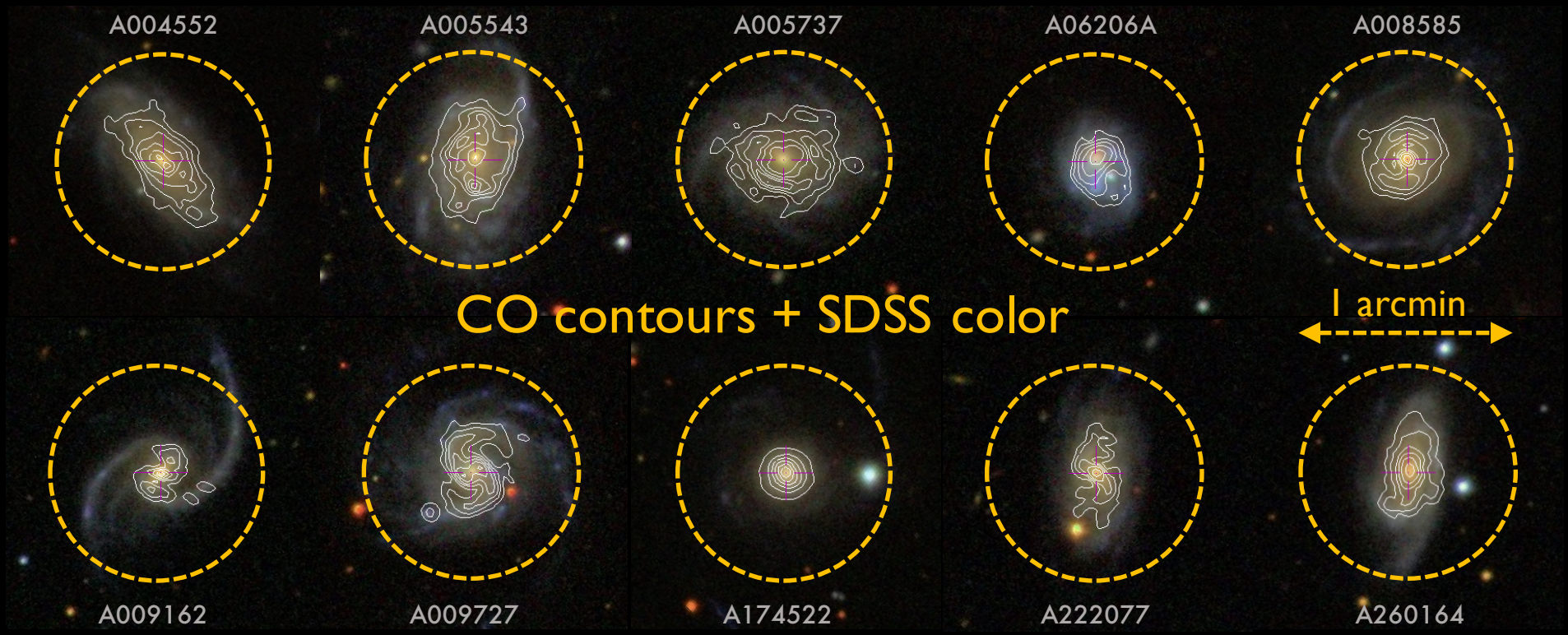
CO
single-dish
Follow up of
HI Monsters

Most HI monsters DO have large molecular gas mass
→ True cool gas monsters in low-z
→ Distinct in gas morphology and SF mode?

→ ALMA follow-up (Cycle 3) of 10 cool-gas monsters
which are accessible from the ALMA site
(12CO 1-0 using Band 3: ~40 min per target including overhead)

ALMA 12CO(1-0) observations of cool-gas monsters (Chung, et al. in prep)

ALMA synthesized beam ~ 2~3" (~2.5 kpc @ 200 Mpc)



- Overall asymmetry of the CO disk and spiky (?) features in the outer are common (as seen in local normal galaxies or merging systems; Kuno et al. 2007; Ueda et al. 2014).
- One shows a clear hole in the center and one shows a partial hole (both red in opt).
- Half light radius: (0.30 $\pm$ 0.10) x R_{25} – Blue galaxies are generally compact in CO.

Σ_{Star} vs. $\Sigma_{\mathrm{H_2}}$ of Cool-Gas Monsters

Kennicutt-Schmidt relation of cool-gas monsters

SFR density maps constructed from GALEX FUV + WISE band 4 following the prescription of Bigiel et al. (2008)

$$\Sigma_{SFR} \propto (\Sigma_{H2})^n$$

→ HI Monsters $n \sim 0.29$ (or 0.39 for $r/r_{25} < 0.5$)

→ Significantly lower than the typical index of KS law (1 ~ 1.4)

→ Sub-thermal? (Azeez et al. 2016)

The origin of gas (accretion from filaments and/or neighbors?) of cool-gas monsters to be further studied (8 out of 10 cool-gas monsters do have nearby companions or groups within 1 Mpc radius at similar redshift).

Galaxies that are extremely rich in cool-gas, exist: the ALMA data clearly show that they can well be offset from the typical Kennicutt-Schmidt law, unlike the theoretical prediction.

Mattention to normal to quiescent galaxies at all redshift – except for the gas content – will be needed, in order to get better understanding of galaxy formation and evolution. The ALMA will be the pioneer in probing such galaxy populations.

Summary
ALMA obs of
Cool-Gas
Monsters

Thank you!

Special thanks to those who are involved with the maintenance, data acquisition and reduction…!